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Neutron Measurements at the Neutrino Wonder Building with a Precision Long Counter

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June 16, 1981

Experiment 531 uses emulsions which are sensitive to neutron backgrounds. Several tests have been done by the experimenters using scintillation counters which suggest a correlation of the neutron background in the Neutrino Wonder Building with the operation of the Proton-East beam line for Experiment 516 in the Tag Photon Laboratory[1]. Experiment 531 has a concern that operation of the N7 beam line will create a serious background problem for their emulsion experiment. The precision long counter in the Radiation Physics Mobile Environmental Radiation Laboratory (MERL) was used by the author in an attempt to measure the neutron field at the Neutrino Wonder Building both with just PE running and with PE running simultaneously with low intensity N7 targeting in Enclosure 103. A measurement of the neutron flux was also made at positions intermediate between the Wonder Building and the well known "hot spot" on top of Proton Enclosure EE1 to check if skyshine from this enclosure was a plausible source of the background at E531.

1. Instrumentation

The precision long counter is a detector which measures neutron fluxes with a sensitivity which is relatively independent of neutron energy over several decades from thermal to about 10 MeV. The sensitivity to muons is easily removed by choosing an appropriate threshold. The calibration of the detector used in this work has been described in a separate note which for convenience is included here as

Appendix I. From Appendix I it is seen that the sensitivity is about 4 counts cm^2/neutron in the energy range where the detector is well tested.

The cosmic ray background with this counter has been measured to be approximately 100 counts/hour. (25 neutrons cm^{-2} hr^{-1})

2. Measurement of Neutron Flux Without N7 Running

The neutron flux was measured at 4 locations on 12/26/80 with PE operating at approximately 5×10^{12} protons per pulse, P West at 2×10^{12} protons/pulse, and NO at 1.5×10^{13} protons per pulse at 400 GeV 10 second cycle time. P Center was off during this period. Data was collected on two scalers; one gated on during the spill and the other gated on approximately 0.5 sec. later for the same time duration as the spill to measure the background. Counts from the PE SEM pulse train were summed to normalize the data. All beam intensities (PE, PW, and NO) were stable ($\pm$ 20 per cent) during the time of the measurements. Background subtracted data collected at 4 locations on a line between Location 1 (beside the E531 Porta Kamp about 20 feet downstream of the Wonder Building) and the center of the roof of the EE1 Enclosure are displayed on Table I. Also in Table I are two estimates of the expected falloff in neutron flux as a function of distance from EE1. One of these is based upon a simple inverse square dependence and the other is based upon skyshine measurements at other Laboratories[2]. As one can see, the fluxes measured are consistent with skyshine from EE1.

Extending the $1/r^2$ falloff to the nearest point of the Fermilab site boundary (approximately 1830 meters from EE1) one obtains a neutron flux of about 0.003 neutrons/cm^2 per 10^{12} protons. During the entire FY 1981 running period, 3.2×10^{18} protons were targeted on PE resulting in a total neutron flux of 9600 n/cm^2. Assuming an unrealistically hard skyshine spectrum having an average energy of 10 MeV and referring to p 69 of ref 2, this would represent a dose equivalent of only 0.4 mrem during this period. Other results indicate that the falloff is approximately $1/r^2$ at large distances and that the neutrons are indeed from skyshine rather than high energy neutrons penetrating the earth.[3]

3. Measurement of Neutron Flux at Neutrino Wonder Building with PE and N7 Operating

The measurements at Location 1 were repeated during the first targeting of beam on a collimator in Enclosure 103 on January 6, 1981. During this period PE was operating at an intensity of approximately 4.5×10^{12} protons/pulse while N7 was operating at an intensity of 4.5×10^{10} proton/pulse. The accelerator was operating at 400 GeV, 10 sec cycle time. During this time a 6" x 3" x 25" plastic scintillator (N531) was monitoring the neutron flux in the Wonder Building next to the emulsions. N531 measures 900 counts/sec from cosmic rays and 1600 counts/sec when PE operates at 5×10^{12} protons/pulse[4]. Thus the suspected PE contribution is about 175 counts/10^{12} above natural background. During 49 spills (approximately 2.2×10^{14} PE protons and 2.2×10^{12} N7 protons, the MERL long counter recorded 83 counts while the counter N531 recorded 133126 counts. From the measurement described above, one would expect 81 long counter counts and 70400 N531 counts for 49 spills at this PE intensity. Thus the long counter did not see a significant contribution from N7 while N531 did. Since N531 did not involve a coincidence requirement to veto muons perhaps muons are being detected from N7. The N531 counter was also somewhat closer to the N7 target location than was the long counter. The measurement should be repeated at higher N7 intensity.

I would like to thank T. Kondo for his help with these measurements.

Table I

Location (Distance from EE1 in meters)	counts/10^{12} protons at PE	$\frac{\text{neutrons}}{\text{cm}^2/10^{12}\text{ protons}}$ at PE	Flux $\left(\frac{\text{neutrons}}{\text{cm}^2\ 10^{12}}\right)$ expected from $\frac{1}{r^2}$ falloff	Flux $\left(\frac{\text{neutrons}}{\text{cm}^2\ 10^{12}}\right)$ expected from Ref. 2 data
1. Neutrino Wonder Building (335 m.)	0.37 ± 0.03	0.09 ± 0.01	0.12	0.07
2. (230 m.)	1.00 ± 0.07	0.25 ± 0.02	0.26	0.24
3. (183 m.)	1.97 ± 0.14	0.49 ± 0.04	0.41	0.41
4. (61 m.) (falloff normalized here)	14.95 ± 0.32	3.74 ± 0.08	---	---

References

1. W. Reay, private communication.

2. H. W. Patterson and R. H. Thomas, Accelerator Health Physics, (Academic Press, New York, 1973), page 438, Fig. 6.68.

3. S. I. Baker, Fermilab Environmental Monitoring Report for Calendar year 1975.

4. Note by T. Kondo, January 5, 1981 (Appendix II).

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R.P. Note #26
Calibration of MERL Long Counter
with a Pu-Be Source

J. D. Cossairt
June 20, 1980

A plutonium-beryllium neutron source was used to measure the detection efficiency of the precision Long Counter located in the Fermilab Mobile Environmental Radiation Laboratory (MERL) which is used to measure the intensity of neutron radiation fields outside of thick shielding. An extensive description of such a Long Counter is given by DePangher and L.L. Nichols[1] while I.M.G. Thompson and A. Lavender[2] give extensive calibration data. It is not the purpose of the present paper to duplicate the detailed descriptions of Refs. 1 and 2, however, a brief functional description is in order. Fig. 1 from Ref. 1 shows the construction of the detector. Neutrons are moderated by the polyethylene shielding to thermal energies. The BF_3 tube is a gas proportional counter which is enriched to 96% ^{10}B. The $^{10}B(n, \alpha)^7Li$ reaction has a large thermal neutron cross section, (3838 barns). The ^7Li nucleus is left in its 478 keV first excited state 95 per cent of the time, while it is in the ground state 5 per cent of the time (Ref. 1). The $\alpha + {}^7Li$ system share 2.9 MeV which is released in the reaction (including the 478 keV gamma ray) and produce a signal which is large relative to competing photon and charged particle (muon) radiation in a mixed field of the type encountered at Fermilab.

The original designers of the detector "fine-tuned" the moderator until an efficiency reasonably independent of neutron energy over a fairly large domain was obtained. Fig. 2 (from Ref. 2) is typical of the efficiency as a function of energy. The efficiency is thus flat over 3 decades of energy and is the reason for the name "Long Counter". To achieve this property the detector must have the front face oriented toward the source of the radiation.

The Long Counter installed in the MERL is somewhat unique in that it is installed in a housing consisting of 3 inches of plywood arranged in a rather complicated geometry comprising wheel wells, walls, etc. The goal of the present work was to measure the response of this detector exposed to a source of neutron outside of the MERL. Fig. 3 shows a block diagram of the electronics along with settings used here. The first measurement consisted of determining the proper threshold to use on the TC213 to discriminate against unwanted gamma rays while counting neutron induced pulses with good efficiency. To accomplish this, the count rate was measured as a function of discriminator threshold for both ^{60}Co source and a plutonium-beryllium (Pu-Be) neutron source. The decay of ^{60}Co is dominated by the emission of 1.17 and 1.32 MeV gamma rays. By comparison, minimum ionizing muons would deposit about 0.2 MeV in traversing the length of the BF_3 proportional counter. This is indeed small compared with the 2.9 MeV deposited due to neutron capture. The spectrum of the Pu-Be source has been reported in Patterson and Thomas[3] and has an average neutron energy of 4.1 MeV. Fig. 4 shows graphs of count rate as a function of threshold for both sources. It is seen that the neutron efficiency is independent of threshold except at very low values. The plutonium source (^{238}Pu) emits gamma rays (less than 150 keV) of which some are seen at low values of the threshold setting. Of course, some 478 keV gammas are also detected due to the deexitation of ^{7}Li. A threshold setting of about 3 volts is a reasonable choice to achieve good neutron efficiency while removing the gammas (and hence muons in a Fermilab mixed field).

After determination of the threshold setting it was desired to measure the count rate in a known neutron field. The neutron field chosen was that of a ^{238}Pu-Be source calibrated by the National Bureau of Standards to emit 4.11×10^6 neutron/sec. The count rate was measured at varying distances of the source from the face of the long counter through the side of the MERL vehicle, thus including the attenuation of the wooden walls of the MERL. Table I shows the results obtained. The distances are measured from the effective center of the counter (see Ref. 2) which is approximately 12 cm inside the front face for an average neutron energy of 4.1 MeV. As one can see, the results in reasonable (10%) agreement with "inverse square law" expectations. Some deviation from inverse square behavior would not be surprising due to the fact that the apparatus is about 4 ft above ground level so that a convenient scattering surface (the earth) is present.

It is now possible to evaluate the efficiency of the long counter in this field since the source strength is known. The results are shown in Table I. The result of 4.3 $\frac{\text{counts}}{\text{n/cm}^2}$ is in reasonable (20%) agreement with results reported in Ref. 2 where a value 3.6 counts/(n/cm^2) was reported. The higher value found here may well be due to the increased quantity of thermalizing material presented by the wooden walls.

For Pu-Be neutrons, Ref. 3 (p 69) gives a value of 6.9 neutrons/(cm$^2\cdot$sec)/(mrem/hr) (quality factor of 8 included) so that the long counter will respond in such a field by 1.07×10^5 counts/mrem or 8.56×10^5 counts/mrad.

Table I

R (cm)	Field n/(cm^2·sec)	Long Counter (counts/sec)	Response Ratio (count/n/cm^2)
100	32.7	121.7	3.72
200	8.12	33.8	4.13
300	3.63	15.3	4.21
400	2.04	8.85	4.33
500	1.31	5.6	4.32

List of Figure Captions

References

1. J. DePangher and L.L. Nichols, Battelle Northwest Laboratories Report BNWL-260, June 1966.

2. I.M.G. Thompson and A. Lavender, IAEA Symposium on Neutron Monitoring for Radiation Protection Purposes, Vienna, 1972, IAEA/SM-167/42.

3. H.W. Patterson and R. H. Thomas, Accelerator Health Physics, (Academic Press, New York, 1973).

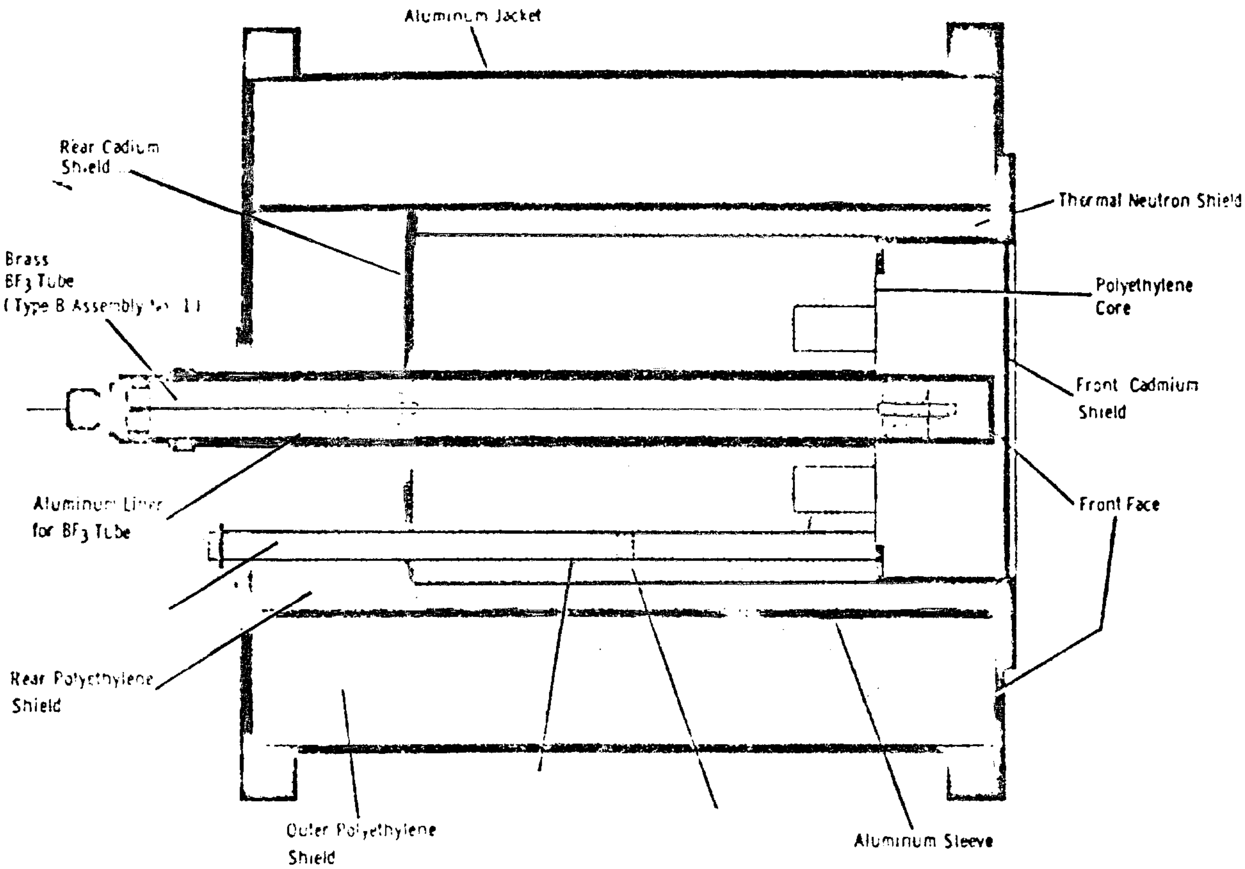
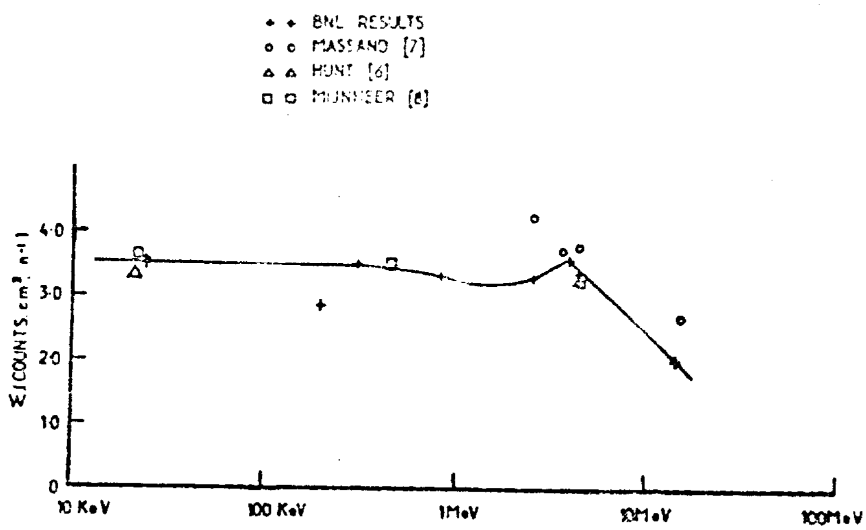

Aluminum Jacket
Rear Cadium Shield
Thermal Neutron Shield
Brass BF3 Tube (Type B Assembly No. 1)
Polyethylene Core
Front Cadmium Shield
Aluminum Liner for BF3 Tube
Front Face
Rear Polyethylene Shield
Outer Polyethylene Shield
Aluminum Sleeve

Figure 1



LONG COUNTER EFFICIENCY

Figure 2

LONG COUNTER ELECTRONICS

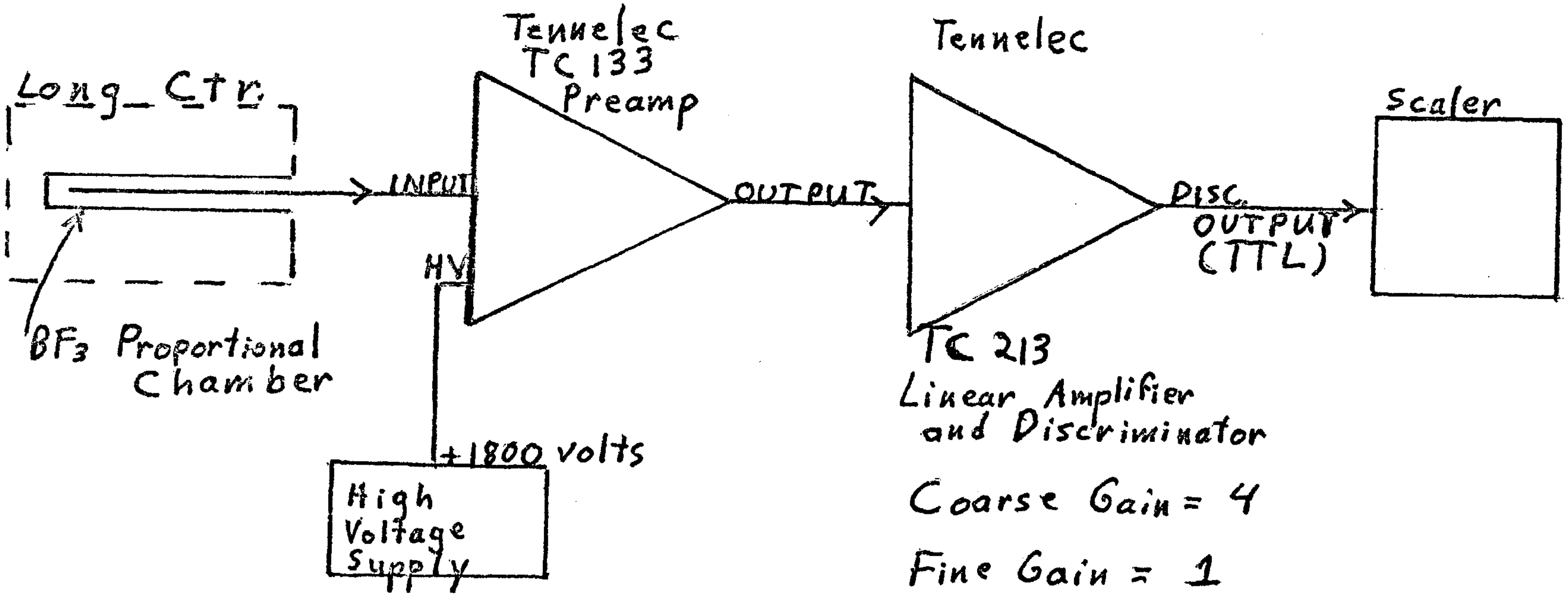


Figure 3

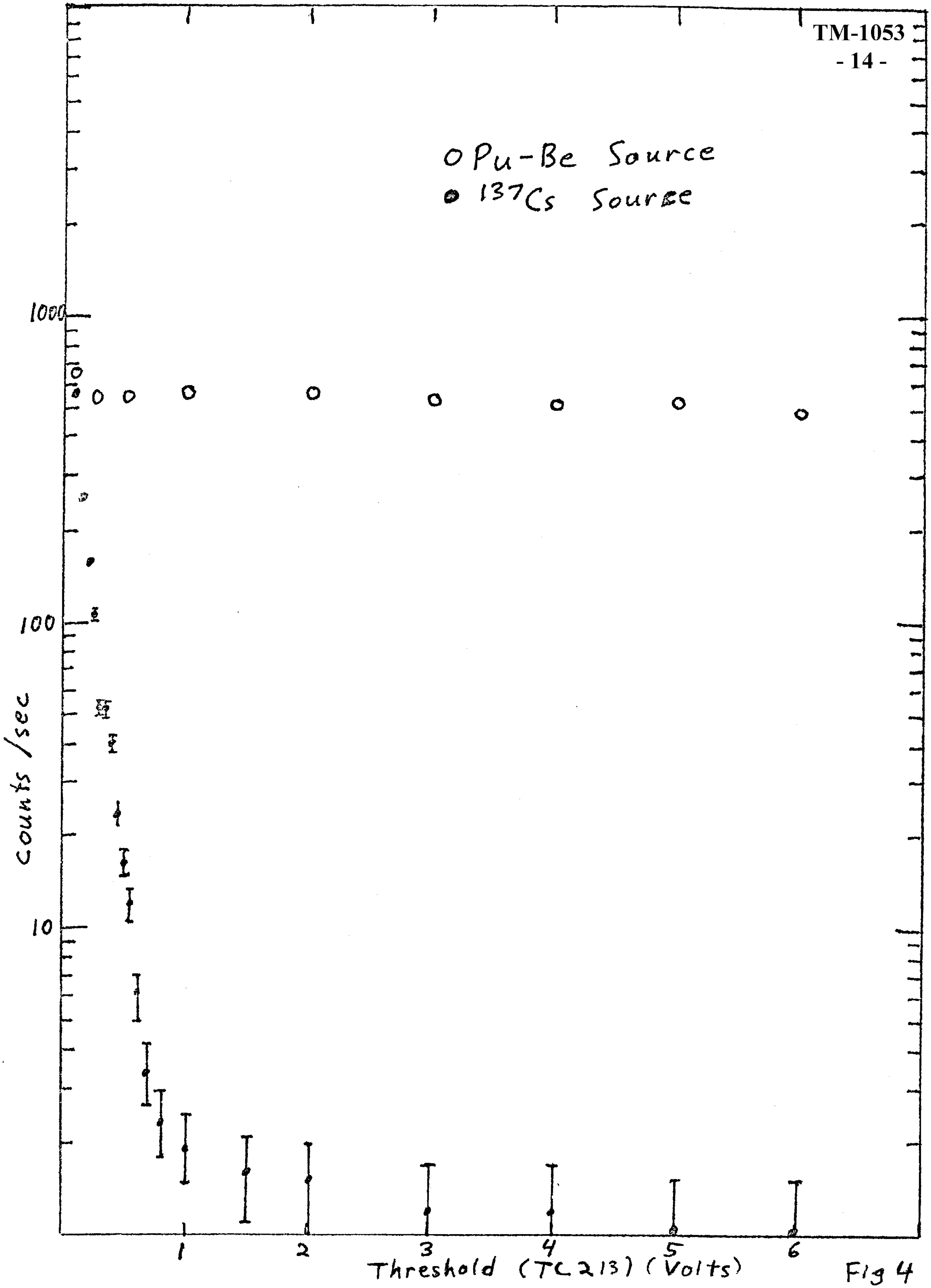

O Pu-Be Source
● 137Cs Source
1000
100
10
counts /sec
1
2
3
4
5
6
Threshold (TC213) (Volts)

Fig 4

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Appendix II

January 5, 1981

TO: MARSHALL MUGGE/CREW CHIEFS - NEUTRINO DEPARTMENT

FROM: TAKA KONDO (E531) T. Kondo

SUBJECT: WONDER BUILDING NEUTRON AND MUON MONITOR

Following devices are set up to monitor the neutron and muon background from N7/N3 beam line

TOF I = 40" x 40" x 3/8" plastic scintillator
Threshold at 0.5 x muon pulse height

Neutron Counter = 6" x 3" x 25" plastic scintillator
threshold at ~ 0.1 MeV (electron equivalent)

The signals are gated by slow spill (1 sec), fast spill (10 ms) and cosmic ray gates (1 sec) and counted on MAC system. They are

Name	Device	Gate	Normal Count	Limit
E531S	TOF I	Slow Spill	150 250*	500
E531F	TOF I	Fast Spill	5	----
N531CR	Neutron	Cosmic Ray	900	----
N531SL	Neutron	Slow Spill	900 1600*	3000

(* P-East on at 5×10^{12})

The limits I propose to protect E531 nuclear emulsion are 3 times of P-East effects. During the 103 beam test, crew chief is assumed to watch E531S and N531SL and shut the N7 beam off whenever one of them exceeds the limits shown above (and call me).

TK:mnm
cc: T. Kirk
R. Stefanski
Crew Chiefs
R. Sood
S. Butala
G. Koizumi
A. Malensek
E531